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I, KIM MARSHALL, MANAGER EXAMINATION SUPPORT AND SALES, hereby certify that the annexed is a true copy of the Provisional specification in connection with Application No. PP 2595 for a patent by LAKE DSP PTY LIMITED filed on 25 March 1998.

I further certify that the annexed specification is not, as yet, open to public inspection.

WITNESS my hand this Twenty Fourth day of September 1998

KIM MARSHALL
MANAGER EXAMINATION SUPPORT AND SALES

P/00/009
Regulation 3.2

AUSTRALIA

Patents Act 1990

PROVISIONAL SPECIFICATION

Invention Title: Sound Signal Processing Apparatus (PAT 51)

The invention is described in the following statement:

GH REF: P24042-AB/PJT:MB

SOUND SIGNAL PROCESSING APPARATUS (PAT 51)

Field of the Invention

The present invention relates to the field of processing of sound signals so as to produce an improved listening experience and, in particular, to produce an improved listening experience over headphones.

Background of the Invention

The use of headphone type devices for listening of sound is well known in society. Unfortunately, when listening to standard stereo type signals or other signals of a more complex nature, for example, Dolby AC-3 format or B-format, it is often the case that a poor "rendering" of the sound to the listener is provided in that the use of headphones result in the sound appearing to come from the middle of the listeners head and fail to provide an "out of head" listening experience where sounds and sources appear to come from outside the listeners head.

Unfortunately, a large amount of product has already been created for stereo listening which utilised a certain headphone standard which results in the playing of sounds such that, when utilising headphones via a standard headphone jack or the like, the sound appears to come from a centralised portion of the listeners head.

It would be desirable if an alternative system could be provided and in particular, if the system could be provided such that previously sold product can be readily adapted, with minimal overhead, so as to provide full and improved listening experience over headphones.

Summary of the Invention

It is an object of the present invention to provide for an improved listening experience over headphones or the like.

In accordance with a first aspect of the present invention, there is provided a method of providing for a compact form of processing of a series of sound output signals for output as stereo signals over a pair of head

phones, the method comprising the steps of convolving a predetermined constructed binaural room response with the sound output signals in real time so as to produce stereo headphone output signals.

In a first embodiment the convolution is performed in utilising a skip protection processor unit located inside a CD-ROM player unit. In a second embodiment, the convolution is performed utilising a dedicated integrated circuit comprising a modified form of a digital to analog converter. In a third embodiment, the convolution is performed utilising a dedicated or programmable Digital Signal Processor. In a fourth embodiment, the convolution is performed on analog inputs by a DSP processor interconnected between an Analog to Digital Converter and a Digital to Analog Converter. In a fifth embodiment, the convolution is performed on stereo output signals on a separately detachable external device connected intermediate of a sound output signal generator and the headphones the sound output signals being output in a digital form for processing by the external device. In a sixth embodiment, the convolution is performed on stereo output signals on a separately detachable external device connected intermediate of a sound output signal generator and the headphones, the sound output signals being output in an analog form.

Brief Description of Drawings

Notwithstanding any other forms which may fall within the scope of the present invention, preferred forms of the invention will now be described, by way of example only, with reference to the accompanying drawings in which:

Fig. 1 illustrates a first embodiment comprising a binauraliser replacement for a skip protection DSP in a CD or DVD player;

Fig. 2 illustrates a second embodiment comprising a binauraliser replacement for digital to analog converter in a digital audio device;

Fig. 3 illustrates a third embodiment comprising the

incorporation of a binauraliser into a digital audio device;

Fig. 4 illustrates a fourth embodiment comprising the incorporation of a binauraliser into an analog audio device;

Fig. 5 illustrates a stand alone binauraliser; and

Fig. 6 illustrates various possible physical implementations of a stand alone binauraliser.

Description of preferred and other embodiments

The preferred embodiments takes a stereo input signal or, alternatively, where available, a digital input signal or surround sound input signal such as Dolby Prologic, Dolby Digital (AC-3) and DTS, and uses one or more sets of headphones for output. The input signal is binaurally processed so as to improve listening experiences through the headphones on a wide variety of source material thereby making it sound "out of head" or to provide for increased surround sound listening.

The binaural processing can comprise many different techniques however preferably, the technique utilised is as disclosed in Australian Provisional Specification entitled "A System for Producing Spatialization over Headphones (Pat 48)" filed by the present applicants simultaneously herewith the contents of which are hereby fully incorporated by specific cross reference.

Given such a processing technique to produce an out of head effect, a system for undertaking processing can be provided utilising a number of different embodiments. For example, many different possible physical embodiments are possible and the end result can be implemented utilising either analog or digital signal processing techniques or a combination of both.

In a purely digital implementation, the input data is assumed to be obtained in digital time-sampled form. If the embodiment is implemented as part of a digital audio device such as compact disc (CD), MiniDisc, digital video disc (DVD) or digital audio tape (DAT), the input data will already be available in this form. If the unit is

implemented as a physical device in its own right, it may include a digital receiver (SPDIF or similar, either optical or electrical). If the invention is implemented such that only an analog input signal is available, this analog signal must be digitised using an analog to digital converter (ADC).

This digital input signal is then processed by a digital signal processor (DSP) of some form. Examples of DSPs that could be used are:

1. A semi-custom or full-custom integrated circuit designed as a DSP dedicated to the task.
2. A programmable DSP chip, for example the Motorola DSP56002.
3. One or more programmable logic devices.

In a typical implementation the processing may involve the following main building blocks:

1. Convolution with filter characteristics derived from measured or synthesised Head Related Transfer Functions (HRTFs) using the techniques described in the aforementioned patent specification.
2. Recursive filtering using Infinite Impulse Response (IIR) approximations on all or part of impulse responses derived from measured or synthesised HRTFs.
3. "Sparse tap" Finite Impulse Response (FIR) or IIR reverberation filters to simulate the late reflections present in a typical listening environment with speakers. A sparse tap FIR filter refers to one where most of the coefficients are zero and therefore do not need to be calculated.
4. In the case where the embodiment is to be used with a specific set of headphones, filtering may be applied to compensate for any unwanted frequency response characteristics of those headphones.

After processing, the stereo digital output signals are converted to analog signals using digital to analog converters (DAC), amplified if necessary, and routed to the

stereo headphone outputs, perhaps via other circuitry. This final stage may take place either inside the audio device in the case that an embodiment is built-in, or as part of the separate device should an embodiment be implemented as such.

The ADC and/or DAC may also be incorporated onto the same integrated circuit as the processor. An embodiment could also be implemented so that some or all of the processing is done in the analog domain. Embodiments preferably have some method of switching the "binauraliser" effect on and off and may incorporate a method of switching between equaliser settings for different sets of headphones or controlling other variations in the processing performed, including, perhaps, output volume.

In a first embodiment, the processing steps are incorporated into a portable CD or DVD player as a replacement for a skip protection IC. Many currently available CD players incorporate a "skip-protection" feature which buffers data read off the CD in random access memory (RAM). If a "skip" is detected, that is, the audio stream is interrupted by the mechanism of the unit being bumped off track, the unit can reread data from the CD while playing data from the RAM. This skip protection is often implemented as a dedicated DSP, either with RAM on-chip or off-chip.

This embodiment is implemented such that it can be used as a replacement for the skip protection processor with a minimum of charge to existing designs. In this implementation can most probably be implemented as a full-custom integrated circuit, fulfilling the function of both existing skip protection processors and implementation of the out of head processing. A part of the RAM already included for skip protection could be used to run the out of head algorithm for HRTF-type processing. Many of the building blocks of a skip protection processor would also be useful in for the processing described for this invention. An example of such an arrangement is illustrated in Fig. 1.

In a second embodiment illustrated in Fig. 2 the processing is incorporated into a digital audio device (such as a CD, MiniDisc, DVD or DAT player) as a replacement for the DAC. In this implementation the signal processing is performed by a dedicated integrated circuit incorporating a DAC. This can easily be incorporated into a digital audio device with only minor modifications to existing designs as the integrated circuit can be virtually pin compatible with existing DACs.

In a third embodiment, illustrated in Fig. 3, the processing is incorporated into a digital audio device (such as a CD, MiniDisc, DVD or DAT player) as an extra stage in the digital signal chain. In this implementation the signal processing would be performed by either a dedicated or programmable DSP mounted inside a digital audio device and inserted into the stereo digital signal chain before the DAC.

In a fourth embodiment, illustrated in Fig. 4, the processing is incorporated into an audio device (such as a personal cassette player or stereo radio receiver) as an extra stage in the analog signal chain. This embodiment uses an ADC to make use of the analog input signals. This embodiment can most likely be fabricated on a single integrated circuit, incorporating a ADC, DSP and DAC. It may also incorporate some analog processing. This could be easily added into the analog signal chain in existing designs of cassette players and similar devices.

In a fifth embodiment, illustrated in Fig. 5, the processing is implemented as an external device for use with stereo input in digital form. The embodiment can be as a physical unit in its own right or integrated into a set of headphones as described earlier. It can be battery powered with the option to accept power from an external DC plugpack supply. The device takes digital stereo input in either optical or electrical form as is available on some CD and DVD players or similar. Input formats can be SPDIF or

similar and the unit may support surround sound formats such as Dolby Digital AC-3, DTS. It may also have analog inputs as described below. Processing is performed by some form of DSP. This is followed by a DAC. If this DAC can not directly drive headphones, an additional amplifier is added after the DAC. This embodiment of the invention may be implemented on a custom integrated circuit incorporating DSP, DAC, and possibly headphone amplifier.

Alternatively, the embodiment can be implemented as a physical unit in its own right or integrated into a set of headphones. It is battery powered with the option to accept power from an external DC plugpack supply. The device takes analog stereo input which is converted to digital data via an ADC. This data is then processed using a DSP and converted back to analog via a DAC. Some or all of the processing may instead by performed in the analog domain. This implementation could be fabricated onto a custom integrated circuit incorporating ADC, DSP, DAC and possibly a headphone amplifier as well as any analog processing circuitry required. The embodiment may incorporate a distance or "zoom" control which allows the listener to vary the perceived distance of the sound source.

In a preferred embodiment this control is implemented as a slider control. When this control is at its minimum the sound appears to come from very close to the ears and may, in fact, be plain unbinauralised stereo. At this control's maximum setting the sound is perceived to come from a distance. The control can be varied between these extremes to control the perceived "out-of-head"-ness of the sound. By starting the control in the minimum position and slider it towards maximum, the user will be able to adjust to the binaural experience quicker than with a simple *binaural on/off* switch.

Implementation of such a control can comprise utilizing different sets of filter responses for different distances. Example implementations are shown in Fig. 6. As a further

alternative, an embodiment could be implemented as generic integrated circuit solution suiting a wide range of applications including those set out previously.

The embodiment can be implemented as an integrated circuit incorporating some or all of the building blocks mentioned in the above implementations. This same integrated circuit could be incorporated into virtually any piece of audio equipment with headphone output. It would also be the fundamental building block of any physical unit produced specifically as an implementation of the invention. Such an integrated circuit would include some or all of ADC, DSP, DAC, memory I^2S stereo digital audio input, S/PDIF digital audio input, headphone amplifier as well as control pins to allow the device to operate in different modes (eg analog or digital input).

It would be further appreciated by a person skilled in the art that numerous variations and/or modifications may be made to the present invention as shown in the specific embodiments without departing from the spirit or scope of the invention as broadly described. The present embodiments are, therefore, to be considered in all respects to be illustrative and not restrictive.

We Claim:

1. A method of providing for a compact form of processing of a series of sound output signals for output as stereo signals over a pair of head phones, said method comprising the steps of:

convolving a predetermined constructed binaural room response with said sound output signals in real time so as to produce stereo headphone output signals.

2. A method as claimed in claim 1 wherein said convolution is performed in utilising a skip protection processor unit located inside a CD-ROM player unit.

3. A method as claimed in claim 1 wherein said convolution is performed utilising a dedicated integrated circuit comprising a modified form of a digital to analog converter.

4. A method as claimed in claim 1 wherein said convolution is performed utilising a dedicated or programmable Digital Signal Processor.

5. A method as claimed in claim 1 wherein said convolution is performed on analog inputs by a DSP processor interconnected between an Analog to Digital Converter and a Digital to Analog Converter.

6. A method as claimed in claim 1 wherein said convolution is performed on stereo output signals on a separately detachable external device connected intermediate of a sound output signal generator and said headphones said sound output signals being output in a digital form for processing by said external device.

7. A method as claimed in claim 1 wherein said convolution is performed on stereo output signals on a separately detachable external device connected intermediate of a sound output signal generator and said headphones, said sound output signals being output in an analog form.

8. A method as claimed in any previous claim further comprising utilizing a variable zoom control to alter a perceived distance of the binaural room response.

9. An apparatus when implementing the method as set out in any of claims 1 to 8.

Dated this 25th day of March 1998

Lake DSP Pty Limited
By their Patent Attorneys
GRIFFITH HACK

Abstract

A method of providing for a compact form of processing of a series of sound output signals for output as stereo signals over a pair of head phones is disclosed, the method comprising the steps of convolving a predetermined constructed binaural room response with the sound output signals in real time so as to produce stereo headphone output signals. In a first embodiment the convolution is performed in utilising a skip protection processor unit located inside a CD-ROM player unit. In a second embodiment, the convolution is performed utilising a dedicated integrated circuit comprising a modified form of a digital to analog converter. In a third embodiment, the convolution is performed utilising a dedicated or programmable Digital Signal Processor. In a fourth embodiment, the convolution is performed on analog inputs by a DSP processor interconnected between an Analog to Digital Converter and a Digital to Analog Converter. In a fifth embodiment, the convolution is performed on stereo output signals on a separately detachable external device connected intermediate of a sound output signal generator and the headphones the sound output signals being output in a digital form for processing by the external device. In a sixth embodiment, the convolution is performed on stereo output signals on a separately detachable external device connected intermediate of a sound output signal generator and the headphones, the sound output signals being output in an analog form.

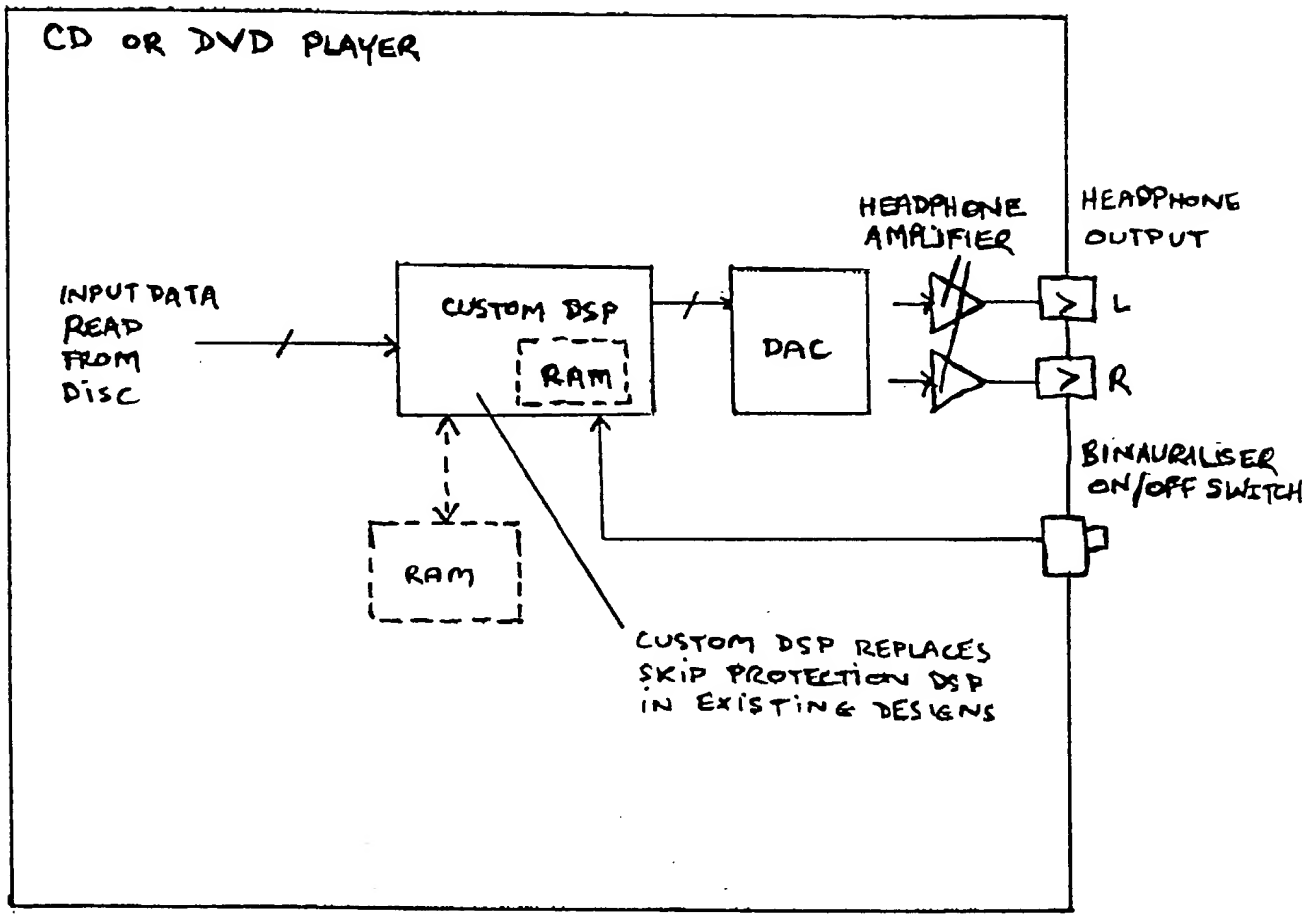
CD OR DVD PLAYER
INPUT DATA READ FROM DISC
CUSTOM DSP
RAM
DAC
HEADPHONE AMPLIFIER
HEADPHONE OUTPUT
L
R
BINAURALISER ON/OFF SWITCH
RAM
CUSTOM DSP REPLACES SKIP PROTECTION DSP IN EXISTING DESIGNS

FIG. 1

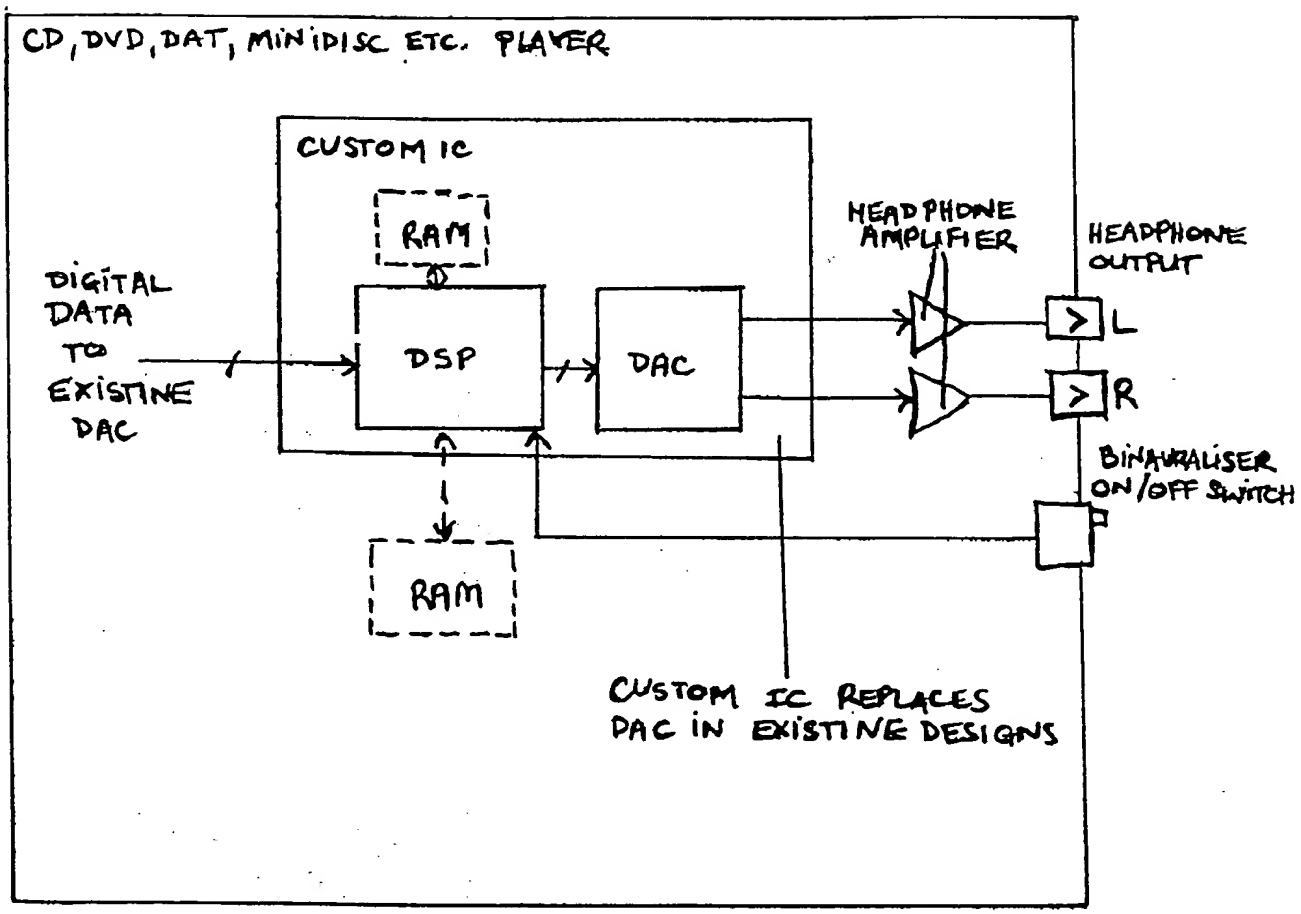
CD, DVD, DAT, MINIDISC ETC. PLAYER
CUSTOM IC
RAM
DIGITAL DATA TO EXISTING DAC
DSP
DAC
HEADPHONE AMPLIFIER
HEADPHONE OUTPUT
L
R
BINAURALISER ON/OFF SWITCH
RAM
CUSTOM IC REPLACES DAC IN EXISTING DESIGNS

FIG. 2

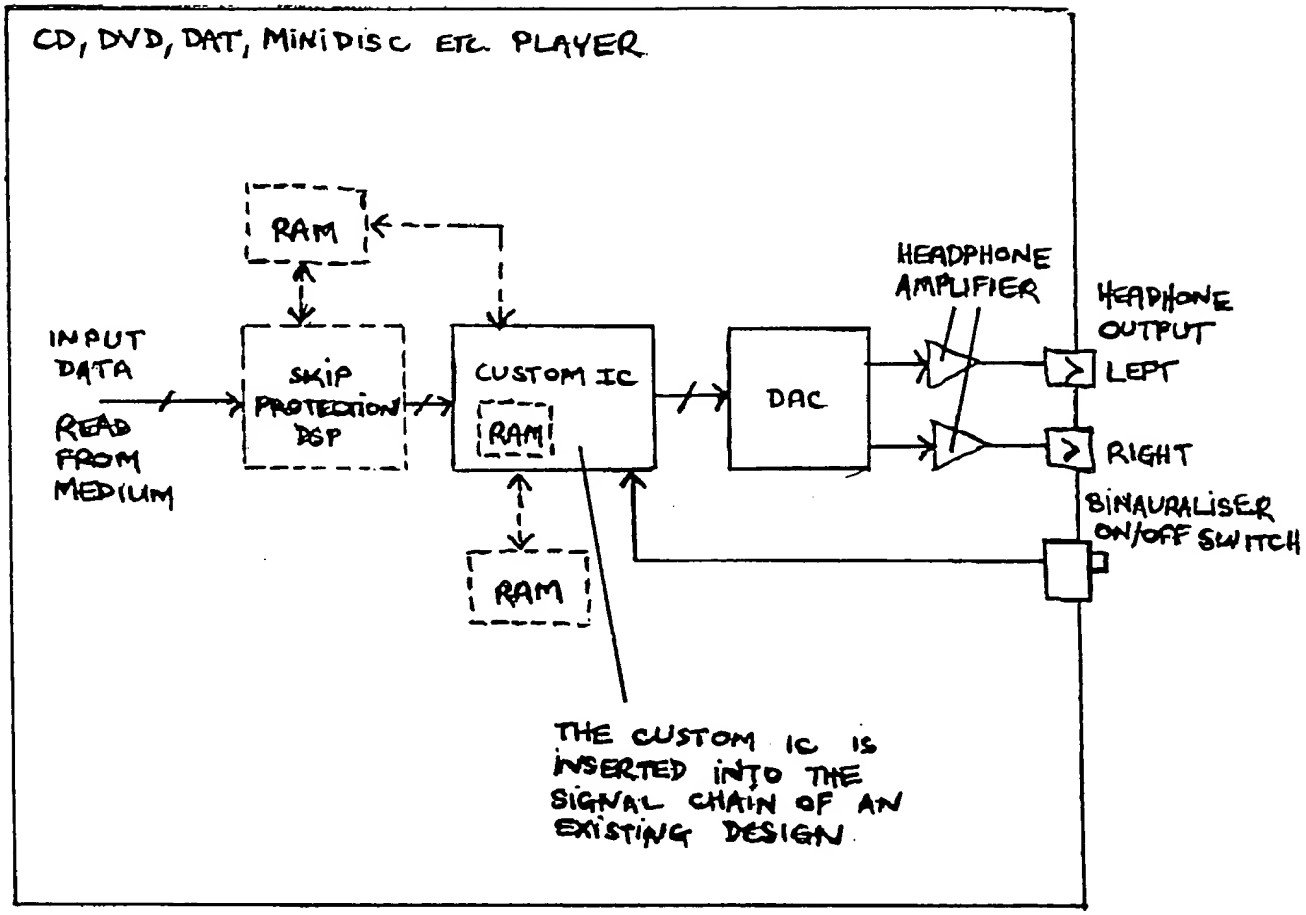
CD, DVD, DAT, MINIDISC ETC. PLAYER
RAM
INPUT DATA
READ FROM MEDIUM
SKIP PROTECTION DSP
CUSTOM IC
RAM
RAM
DAC
HEADPHONE AMPLIFIER
HEADPHONE OUTPUT
LEFT
RIGHT
BINAURALISER ON/OFF SWITCH
THE CUSTOM IC IS INSERTED INTO THE SIGNAL CHAIN OF AN EXISTING DESIGN.

FIG. 3

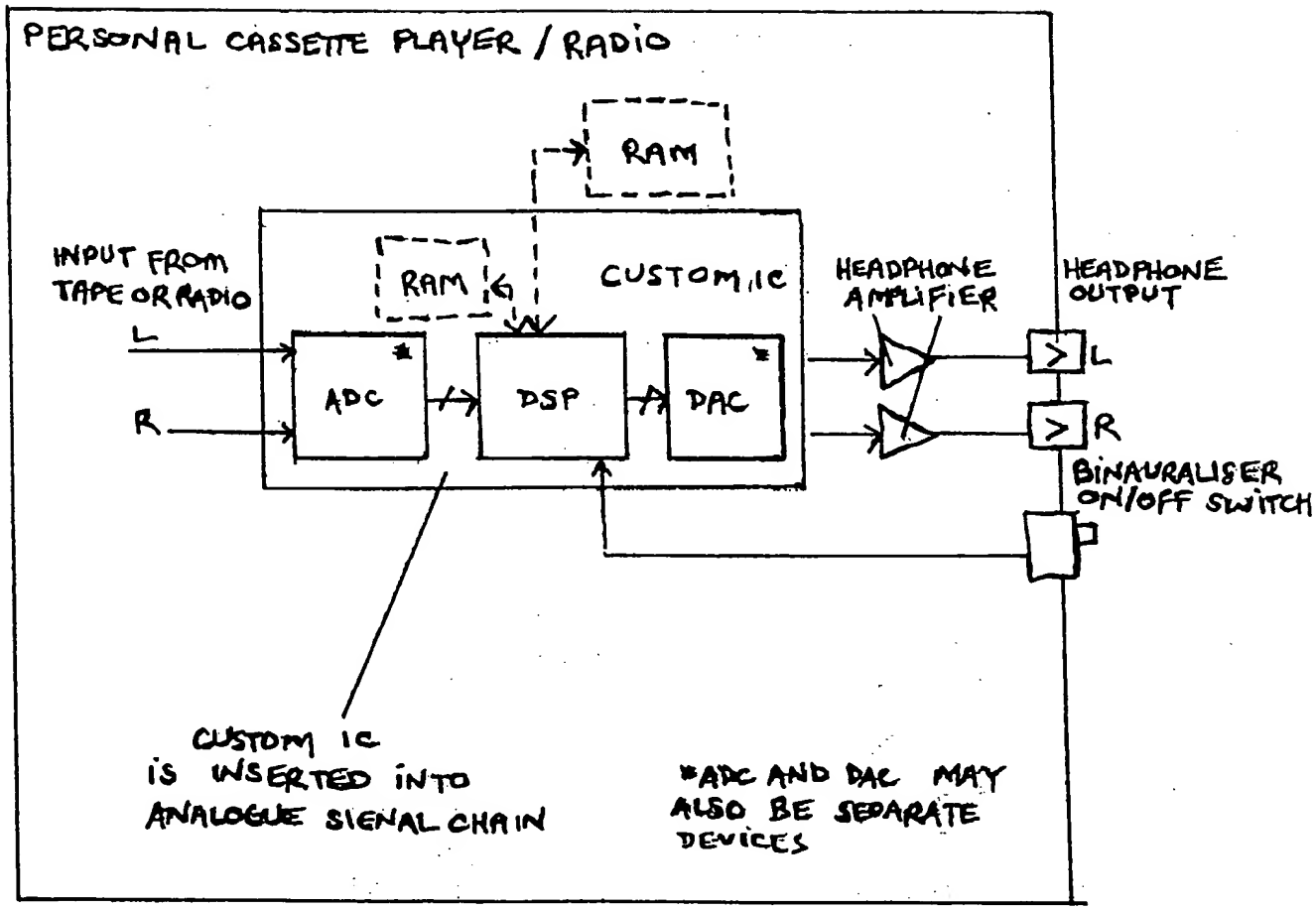
PERSONAL CASSETTE PLAYER / RADIO
RAM
RAM
CUSTOM IC
INPUT FROM TAPE OR RADIO
L
R
ADC *
DSP
DAC *
HEADPHONE AMPLIFIER
HEADPHONE OUTPUT
L
R
BINAURALISER ON/OFF SWITCH
CUSTOM IC IS INSERTED INTO ANALOGUE SIGNAL CHAIN
*ADC AND DAC MAY ALSO BE SEPARATE DEVICES

FIG. 4

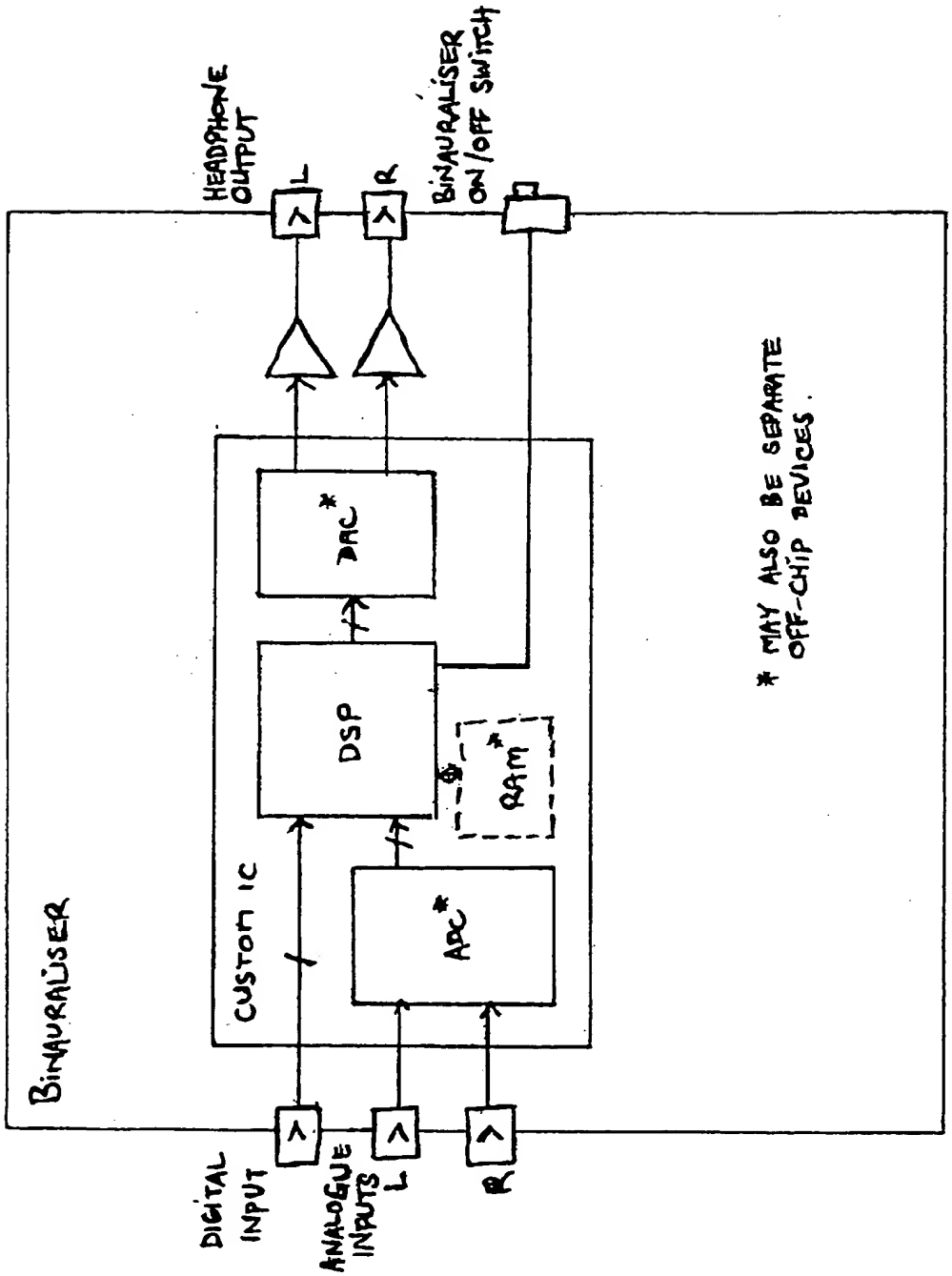
HEADPHONE OUTPUT
L
R
BINAURALISER ON/OFF SWITCH
BINAURALISER
CUSTOM IC
DAC*
DSP
RAM*
ADC*
* MAY ALSO BE SEPARATE OFF-CHIP DEVICES.
DIGITAL INPUT
ANALOGUE INPUTS
L
R

FIG. 5

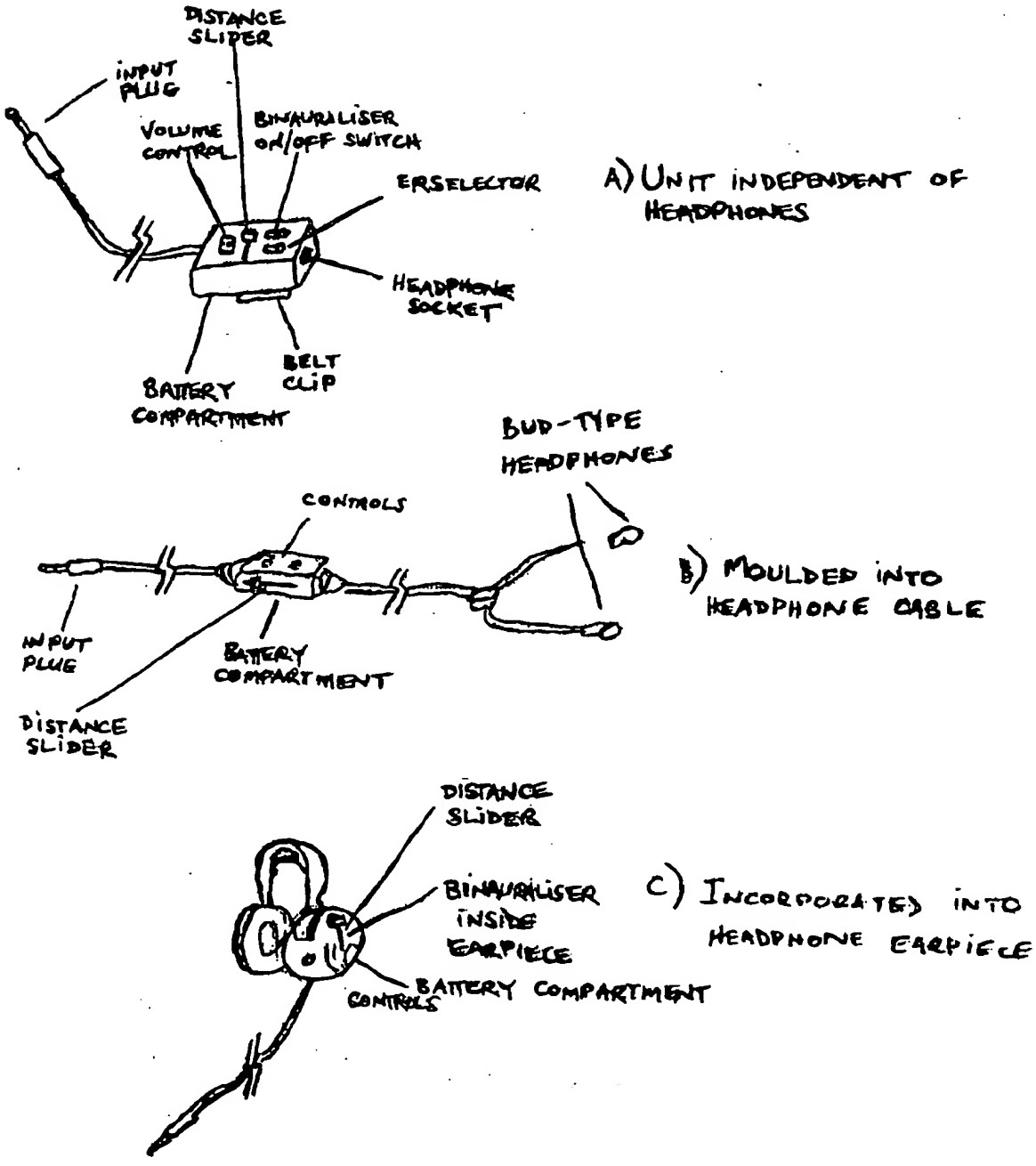
DISTANCE SLIPER
INPUT PLUG
VOLUME CONTROL
BINAURALISER ON/OFF SWITCH
ERSELECTOR
HEADPHONE SOCKET
BELT CLIP
BATTERY COMPARTMENT
A) UNIT INDEPENDENT OF HEADPHONES
BUD-TYPE HEADPHONES
CONTROLS
INPUT PLUG
BATTERY COMPARTMENT
DISTANCE SLIDER
B) MOULDED INTO HEADPHONE CABLE
DISTANCE SLIDER
BINAURALISER INSIDE EARPIECE
CONTROLS
BATTERY COMPARTMENT
C) INCORPORATED INTO HEADPHONE EARPIECE

FIG. 6